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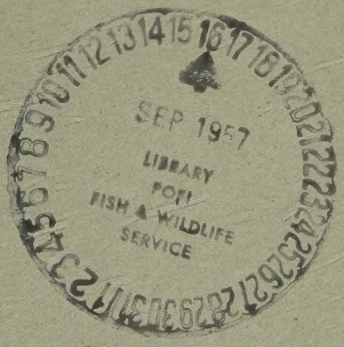
On the Herring of the Southern North Sea

D. H. CUSHING and A. C. BURD

Fisheries Laboratory, Lowestoft



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PREFACE

In 1955, operators in the East Anglian herring fishery were much dismayed by poor landings. They had not expected a good season because Full Moons fell on dates known to be unfavourable. Then, when the season opened, the weather and behaviour of the herrings seemed against them also; there was little or no improvement as the season went on and fishermen and others noted that this was the third season in succession when the fishery in November fell below expectation. The season of 1955 failed in October too; but it was the repeated disappointment of November that seemed most ominous.

In March 1956, the directors of the English and Scottish research staffs were able to make a short agreed statement, which follows this preface. It had proved possible to arrive at an appraisal based on data: the whole of the disappointment of October was, in the absence of evidence to the contrary, allotted to natural causes; so was that of November partly. There remained, however, a substantial part of the failure in November that was, on the data, ascribed to increase in fishing in recent years.

Dogmatism is out of place in this subject: both man-made and natural causes are involved, and in addition, data on highly migratory fisheries are always difficult to interpret. In this situation, we have chosen to hold rather closely to what the data show, on the simplest acceptable interpretations. The truth may well prove to be more complicated than we have set out below; but the simpler of two possible interpretations is likely to be the better guide for action.

Proceeding in that way, as set out in the pages that follow, we finish by advising that if the November fishery is worth preserving, it would be against the evidence to believe that it can recover and continue without some measure of conservation of the adult herring, of three years old and more. The data will not take us farther than that, as yet. A somewhat better appreciation would be possible on the basis of further information; but time alone will give final and certain answers. In the meanwhile fisheries of great value may be reduced or lost.

Michael Graham

Fisheries Laboratory,
Lowestoft.
19th December, 1956.

THE EAST ANGLIAN HERRING FISHERIES, 1955

Statement by the Directors of Fisheries Research

Both natural causes and the increased fishing of recent years appear to have played a part in affecting the landings of herring off East Anglia in 1955, when results gave such serious disappointment. There was disappointment in October, when the younger fish are expected, and again in November, when the older ones generally come. Catches off East Anglia tend to be greater near the Full Moon. In 1955 only one Full Moon fell within the proper season, instead of two as happens rather more frequently. Also, the weather in which the season opened was calm and warm, and winds were northerly: which are usually accepted as unfavourable conditions. However, environmental conditions did not, as far as their effects can be estimated, sufficiently account for the deficiency in landings: there was also shortage of herrings available in the Southern Bight of the North Sea.

The deficiency in October, 1955 was mainly due to the recruit year class hatched in 1952 making a very poor showing, for which there is no evidence of any but natural causes. On the other hand, the deficiency of November, 1955 can be ascribed to a substantial degree to low catches of fish older than three years. Since 1953, fewer older fish appear to have survived to return year by year; and the information available indicates that this has also been a period of increased fishing effort in the Southern Bight of the North Sea. A similar conjunction of lower survival rate and increased estimated effort occurred in 1935/38 and, taking account of that repetition, it would be unreasonable not to associate less survival with more fishing.

Although 1955 was in some ways unfavourable in natural conditions, the condition of the plankton since 1950 has been unusually favourable to herring growth and, probably, survival. The probability of that condition persisting for only a term of years is an additional reason for anxiety about the future.

More northerly herring fisheries in the North Sea gave good results in 1955, and it is somewhat disturbing that those good results could be ascribed to the same temporary conditions.

Scientific papers on the subject are in preparation.

Michael Graham, *Fisheries Laboratory, Lowestoft.*

C. E. Lucas, *Fisheries Laboratory, Aberdeen.*

15th March, 1956.

On the Herring of the Southern North Sea

I. THE DOWNS HERRING

Introduction

The autumn spawned herring in the North Sea have been separated by many workers into the Bank "race" and the Downs "race". Racial differences in a number of measured characters were established by Heincke (1898), and further differences are associated with time and place of spawning. The Bank fish spawn between July and October from the Scottish coasts to the Dogger, whereas the Downs fish spawn between November and February in the region of the Straits of Dover. An attempt will be made in this paper to support the distinction and to confirm that a separate name "Downs Herring stock" is possibly still justified.

The herring was first examined over the whole North Sea by Bjerkan (1917), who worked on the collections from the International Investigations. For a number of years samples were taken from the four main regions, Shetland, Scotland, Dogger and East Anglia; each sample was examined for age. Bjerkan must have known very well of Lea's use of the age distributions of the Norwegian herring (1919), marked with the 1904 year class, to show the unity of the stock in all the major fisheries in Norway. So he classed the samples by their prominent year classes, e.g., the 1904 year class did appear at Utsire and in the Shetland fishery; but in the Southern Bight, it was the 1908 year class that was prominent. By this method he distinguished four different stocks: at Shetland, the Scottish North-east coast, the Dogger and East Anglia. For our present purpose we are concerned only with the distinction between the Dogger or Bank herring and the East Anglian or Downs herring.

An extension of Bjerkan's method is to identify stocks by the likeness of age distributions. We should first consider to what extent this method might be misleading through inefficient sampling. Age distributions from the same stock may differ either because of poor sampling procedures on the market or because of a sampling difference due to other circumstances of the fishery itself. Thus, taking a market example, the age distributions in East Anglia in October are very different to those in November, because the older fish come late into the fishery. Taking a fishery example, the age distributions during the Channel trawl fishery at the Hinder are different from those off Boulogne, possibly because the three year olds may spawn in the region of the Hinder. We can deal with the first because it is within our power to make sure that we sample the East Anglian fishery on the market in both October and November; whether or not we obtained sufficient samples of three year olds at Boulogne would depend on the extent to which vessels go from there to fish the Hinder-Sandettié region. Consequently we cannot expect the age distributions in the different fisheries to correspond exactly.

The Unity of the Southern Bight Fisheries

The following modern fisheries would from their location and season be expected to be on Downs herring (Fig. 1a):

The East Anglian drift-net fishery in October and November, for maturing and full herring.

The Dutch and German drift-net fisheries off the East Anglian coast in October and November, for maturing and full herring.

The Belgian pelagic trawl fishery for full and spawning herring.

The Straits of Dover fishery for full and spawning herring, which extends from the North Hinder to Beachy Head and Le Vergoyer; it is exploited by trawlers from Germany, Holland, Belgium and France in November, December and January.

The Belgian spent herring fishery in December and January.

From October onwards in the Southern Bight, fish are found in maturity Stage IV-V; they become riper as the season advances, and spent fish are usually reported towards the end of November. The full herring fishery continues until the end of the year and the spent herring fishery goes on into January and February. It is reasonable to suppose that the fish move southward to spawn in the Straits and that they move north from the spawning grounds as spents.

The concept of the stocks contributing to Southern Bight fisheries uniting into one spawning migration has been tacitly accepted for a long time and so strict racial comparisons have not been made. However, Hodgson (1950) has compared the l_1 distributions in East Anglia and in the Boulogne fishery in 1949 and he found that they were very much alike. Cushing (1955) has compared mean vertebral counts in each year from 1948-52, from a number of fisheries including East Anglia, Boulogne and Ostend; it was shown that in general the vertebral counts of samples from these three Southern Bight fisheries were higher than those of samples of the Bank fisheries. However, the East Anglian vertebral counts were consistently somewhat lower than those from the Boulogne and Ostend fisheries; this is probably associated with the marked temperature differences between the Hinder-Sandettié grounds in November and the Vergoyer in January.

If the fisheries in the Southern Bight exploit a common stock, the evidence for its unity will not rest solely on lack of meristic difference, but on the positive fact of a common biological character. For example, most of the fish in the Southern Bight probably spawn between November and January in time and between the North Hinder Bank and Le Vergoyer in space. The spawning grounds are not known in the strict sense, but we do know from the distributions of the fisheries that the trawlers aggregate in certain places. which are the same as those shown by echo survey. Fig. 1 shows: (a) the banks between which the major fisheries take place, (b) an echo survey carried out in 1951 and (c) an echo survey carried out by Renou and Tchernia in 1946 (1947).

Table I shows percentage age distributions from different parts of the spawning ground fisheries as samples from Boulogne:

Table I: *Age distributions from different parts of the Straits spawning grounds, in percentages, for November and December* 1949
(Ancellin, 1951)

		2	3	4	5	6	7	8	9	10	10+
Dyck-Sandettié	Nov.	–	53	31	8	3	3	1	–	1	–
	Dec.	–	22	18	14	10	18	11	3	3	1
Nord Somme	Nov.	–	16	46	22	6	7	3	–	–	–
	Dec.	–	3	24	19	9	22	10	9	3	1

In both the main regions of the fishery, Sandettié and Nord Somme, the younger fish appear in November and the older fish in December. Similarly, the older fish come later into the East Anglian fishery, in November, as has been shown so clearly by Hodgson (1939). The sequence of older following younger is unique amongst herring fisheries and the fact that it holds in two of the Southern Bight fisheries that are sampled for age adds support to the conclusion that the stock is a common one. We may provisionally conclude that the stock is truly common to all three fisheries.

It is instructive to compare the age distributions as sampled from each of three laboratories studying the stocks, Lowestoft, Boulogne and Ostend. Fig. 2 compares age distributions for the pre-war years and for 1952. The data from Boulogne are expressed as

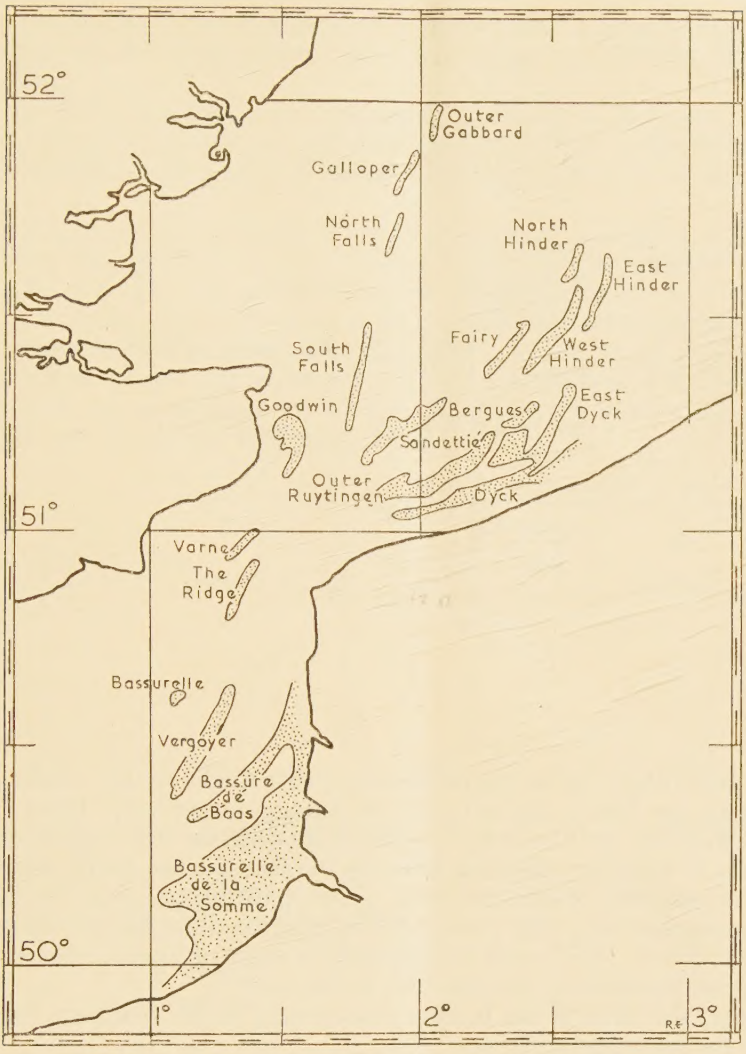

Fig. I, 1(a): *The banks in the region of the Straits of Dover on which the herring probably spawn.*

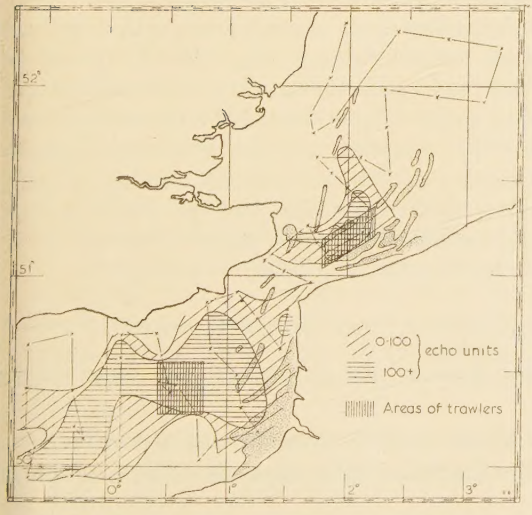

Fig. I, 1(b): *An echo survey carried out in December* 1951, *when trawlers were working south of Beachy Head.*

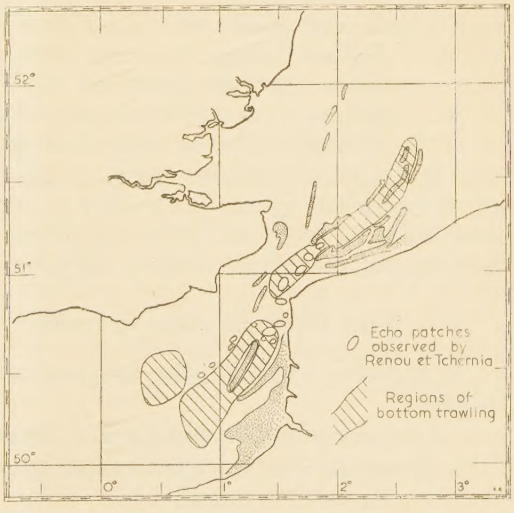

Fig. I, 1(c): *An echo survey carried out by Renou and Tchernia* (1947).

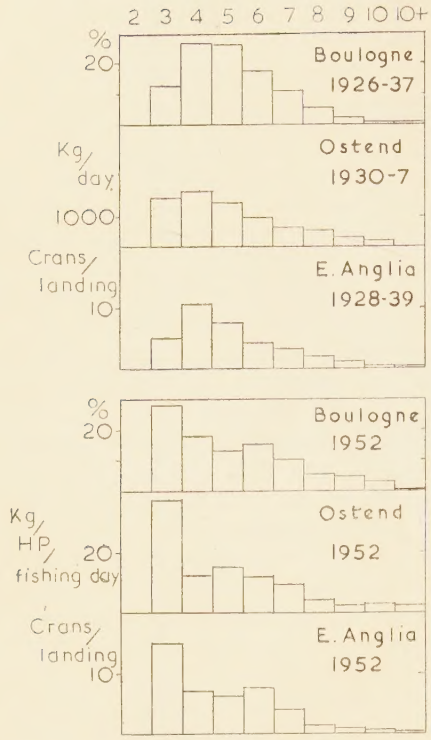

Fig. I,2: *The unity of the Southern Bight stocks.*

the means of percentages; those from Ostend and East Anglia are the means of percentages multiplied by kg. per fishing day and crans per landing respectively. There is a fair degree of likeness between the age distributions, particularly when the following points are recalled: that differences in sampling efficiency between the fisheries are likely, merely because of the different accessibility of different parts of the spawning grounds, e.g., three year old fish are better represented in the Ostend fishery and the older fish are better represented in the Boulogne fishery. This would be explicable in terms of Table I, showing the younger fish spawning in the east and the older fish in the west.

In summary, the unity of the herring stocks found in the Southern Bight fisheries is confirmed on the following evidence:

(a) a likeness of meristic characters;
(b) a common general spawning area and season;
(c) the later arrival of older fish being common to two of the fisheries;
(d) the general likeness of age distributions, taken from these fisheries; this likeness persists through changes in the nature of the fishery, after 1950-1. It will be noticed that the Southern Bight observations in 1952 were taken with three different gears, drift-net (East Anglia), pelagic trawl (Ostend) and herring trawl (Boulogne); hence, differences due to gear selection can play only a minor part.

The last is a most important point, because if the age distributions over a number of years are the same throughout the area, then the age at first recruitment and the mortality rate must surely be the same. If then there were still meristic differences between samples from the three fisheries, they surely would be irrelevant to a study in fisheries biology.

The Distinction between the Downs and Bank Herring

It is worth reopening the question of the classical distinction between these stocks because:

(a) there is undoubtedly some mixture on the nursery grounds east of the Dogger;
(b) appraisal of the effect of fishing in the Southern Bight depends on delineation of the stock involved.

Again we may consider three main kinds of evidence, meristic characters, the distinction by spawning time and the distinction by age distributions, to which we will add that of migration patterns.

Of these, the distinction by meristic characters is already well-known, i.e., that fish spawning on the Dogger have a lower vertebral count than those spawning in the Straits. This is associated with a higher value of keeled scales than that found in samples from the Straits.

The distinction by spawning time is a more obvious one. It is possible to find fish in the Whitby-Silver Pit region in the late summer as fulls or spawners and also as fish in maturity stage IV. The first are probably the fish which spawn on the Dogger and the second may well be those which will spawn in the Straits three to five months later. Mixture therefore takes place in the Whitby and Silver Pit region. An important question is whether this mixture is complete from year to year or whether it is of only small degree. If complete, the mean vertebral counts summed for all ages should be the same; they are, however, significantly different (Buchanan-Wollaston, 1933).

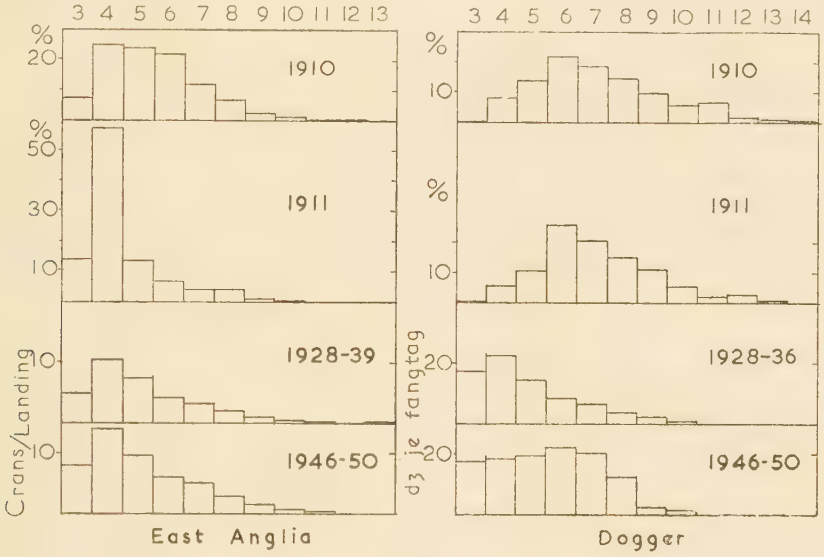

Fig. I, 3: *The distinction between the age distributions sampled on the Dogger and those sampled off East Anglia.*

Fig. 3 compares the age distributions from the Dogger with those from East Anglia which will be taken as representative of the Downs race. The age distributions given for 1910 and 1911 are percentages taken from Bjerkan (1917). Two samples out of the nine used include fish in maturity stages III-V; as individual separation by maturity stages can no longer be made, this error is accepted. The difference between the age distributions shown and those of the remaining samples is only a small one. Those for 1928-50 are percentages multiplied by crans per landing and *dz. je fangtag* for East Anglia and Dogger respectively. It will be noticed that the single sample from East Anglia in 1911 has a strong four year old class; this class is dominant as five and six year old fish in 1912 and 1913 respectively, so it is unlikely that this single sample of fish is merely a bad one. Except for the period 1928-39, the age distributions are markedly different, particularly in 1911 and in 1946-50. The same point can be made by comparing the age distributions from East Anglia and the Dogger from 1952-4 given in Fig. 6, Part II (E. Anglia) and Fig. 10, Part II (Fladen, Gut and Dogger).

Summarizing, the Bank and Downs stocks are distinguished by their separate spawning grounds at different seasons, by a difference in meristic characters and by differences in the age distributions.

On the Return of Tags from different North Sea Fisheries

Herring tagged by Höglund in the Bohuslän fishery have been recovered from the Fladen, Gut, Dogger and Sandettié trawl fisheries. Fish have been recovered after three years at liberty, so the recaptures from any one fishery are not biased by time at liberty. Chart I from Höglund's (1955) paper shows returns from the four fisheries during the period 1949-53. Table II shows the total German trawl landings from the four fisheries for the same period, the total number of tags returned from each fishery and the number of tags returned per ton of fish caught by German trawlers.

Table II: *Number of tags returned per ton of fish caught on the Fladen, Gut, Dogger and Sandettié Fisheries*, 1949-53

	Total tonnage landed (German landings only)	*No. of tags*	*No. of tags* ($\times 10^{-4}$) *per ton fish landed*	
Fladen	205,000	12	0·59	Bank
Gut	50,000	5	1·00	Bank
Dogger	315,000	45	1·43	Bank
Sandettié	150,000	2	0·13	Downs

If the two stocks were the same, one would expect that the number of tags per ton of fish landed would be similar—and not so remarkably different. The table shows that ten times as many tags were returned from the Dogger as from the Sandettié fishery. It will be noticed how close the estimates are for the Fladen, Gut and Dogger fisheries, which have been classed as fisheries for Bank herring.

Fig. 1,4: *A detailed comparison between the age distributions off East Anglia and on the Dogger.*

A Comparison between the Dogger Age Distributions and those from the Southern Bight

Fig. 4 shows the East Anglian age distributions as percentages multiplied by crans/landing; the Dogger age distributions are given as percentages multiplied by *doppelzentnern je*

fangtag. The comparison is made for the years 1924 to 1931. This diagram has been shown to illustrate a paradox, i.e., that although marked differences can be shown in a number of individual years, e.g., 1925, 1930 and 1931, there are certain prominent year classes that occur in both fisheries. The proportions are sometimes different in the two fisheries and a year class does not always retain in one fishery the prominence that it had in the other, e.g., the proportions of the 1921 and 1922 year-classes in 1928-30. However, in view of the arguments given above for separating the Bank and the Downs stocks, this diagram is very important. It shows that something is shared by the two stocks. It might be the same climatic and hydrographical conditions, especially if the stocks shared the same nursery area.

The Common Nursery Ground for the East Anglian and Dogger Stocks

By plotting the drift of larvae, Bückmann (1942) has shown that the region between the Dogger and the Danish coast which is exploited by the industrial fishery is the common nursery area for the Bank and Downs stocks; it includes the Bløden ground, the Tail End, the White Bank, the Coffee Soil, the Oyster ground and the eastern end of the Silver Pit. The *eastern nursery ground* might be a suitable name for these areas.

The major difference between the larvae from the spawning grounds of the two races is one of age, which is, on the average, a difference of four to six months. It is possible that this original difference is the source and basis of all the 'racial' differences between the two stocks, but the early life history still needs more elucidation on the lines being followed by Bertelsen and Popp Madsen (1954 and 1955). Their finding of 1_1 groups that can perhaps be equated to Bank and Downs herring respectively confirms Bückmann's findings from larval drift.

Discussion

A distinction between the Downs and Bank herring has been possibly shown by reason of a difference in age from four to six months. Meristic differences led Heincke (1898) and Schnakenbeck (1927) to separate the stocks as races and their conclusion was supported by the analysis of Schnakenbeck's results by Buchanan-Wollaston (1933). It was, however, Bjerkan (1917) who first showed that the stocks might be separate ones.

In the present paper Bjerkan's method has been extended a little, in that the criterion of the unity of stocks has been taken as the likeness of age distributions.

Such a method implies that sampling for age is efficient, which at this stage in herring investigation may not be so. However, it may be shown that there is a degree of likeness between the age distributions from the Southern Bight fisheries, which contrasts markedly with the degree of difference shown between those from the Southern Bight fisheries and those from the Dogger.

Having made the distinction in this manner between the two stocks, a more detailed comparison revealed a likeness in respect of prominent year classes, which was unexpected. At most, these likenesses implied that the stocks were the same, and at least they implied that different stocks shared the same nursery grounds or the same conditions of upbringing.

The result of Höglund's tagging experiments were used to show that the number of tags returned per ton of fish caught, when fish were tagged at Bohuslän, was greater on the Dogger than at Sandettié by ten times. From this it was concluded that the Downs herring do not visit Bohuslän in great quantities, but that the Bank herring do; this in itself is some separation of the stocks. Further, if the stocks were completely mixed, over five years one would expect roughly equal proportions of tags to turn up on each ground. As it was, two tags appeared on Sandettié as compared with 45 on the Dogger, where the catch was twice as great—so mixing takes place only to a small degree.

In effect this paper has dealt with the separation of the stocks on their spawning grounds and has attributed the separation to the different ages of the fish. In order to complete the job of delineating the stocks and separating the relevant efforts, we need to be able to separate them in the feeding fisheries in the western North Sea, as indeed Wood (1936) has already started to do.

II. NATURAL CHANGES

Several investigators have noticed that since 1951 the character of North Sea herring fisheries, including that off East Anglia in the autumn, has changed. In particular, the younger age groups have become more abundant and the fish are larger for their age.

The fishing effort has changed also. In 1951 a trawl fishery for immature herring in the East Dogger region landed large catches for the first time (38,000 tons); such a fishery might well affect recruitment to the mature stocks in the North Sea. Also in 1951 for the first time a trawl fishery for mature herring in the region of the Straits of Dover made considerable catches (40,000 tons) and one might reasonably expect that such increased fishing effort might affect the age distribution in reducing the numbers of older fish. Both fisheries, east of the Dogger and in the Channel, have been sustained at still higher levels of catch since 1951. Increased fishing could hardly be expected to make younger age groups more abundant, and the possible effects of natural changes need investigating before considering whether effects may be ascribed to fishing in whole or in part.

A Change in the Age Distribution

The most marked change in the age distribution is in the proportion by numbers of three year old fish to four year olds. This is shown in Fig. 1 (from Table 6 in Part III),

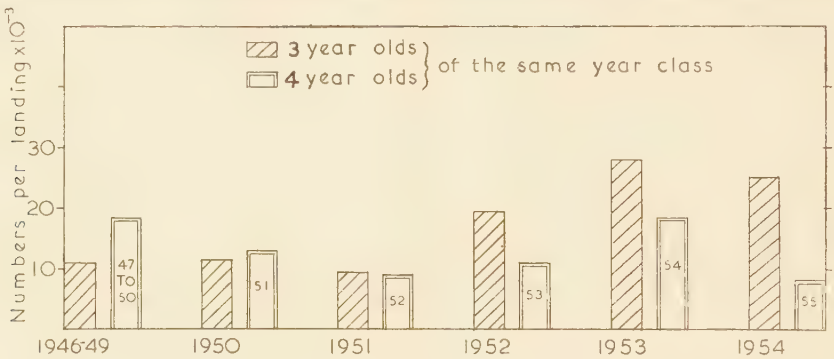

Fig. II, 1: *The change in age distribution in the East Anglian fishery.*

which gives the number per landing of three year old fish and the subsequent numbers per landing of four year old fish of the same year class, from 1950 onwards for the East Anglian fishery. For comparison with recent years, the corresponding averages for 1946-9 are shown on the extreme left of the figure. It will be noticed that the number of four year olds was then nearly twice the number of three year olds, showing that the recruits came into the fishery in at least two main parts, part as three year olds and part as four year olds a year later.

As can be seen in Fig. 1, the change in the age distribution was first noticed in 1951, when the number of four year olds was only 18% greater than the number of three year olds in the previous year. In 1952, the numbers of the three year olds and four year olds of the 1948 year class were the same. In 1953, and subsequently, the proportion of the two age groups, as compared with the 1946-9 period, was reversed, i.e., the number of three year old fish was nearly twice the number of four year old fish of the subsequent year.

The Increase in Length of the Herring

Several investigators, notably Ancellin (1953), Gilis (1954) and Andersson (1954) observed an increase in the length of the three year olds and in the older herring in the southern North Sea.

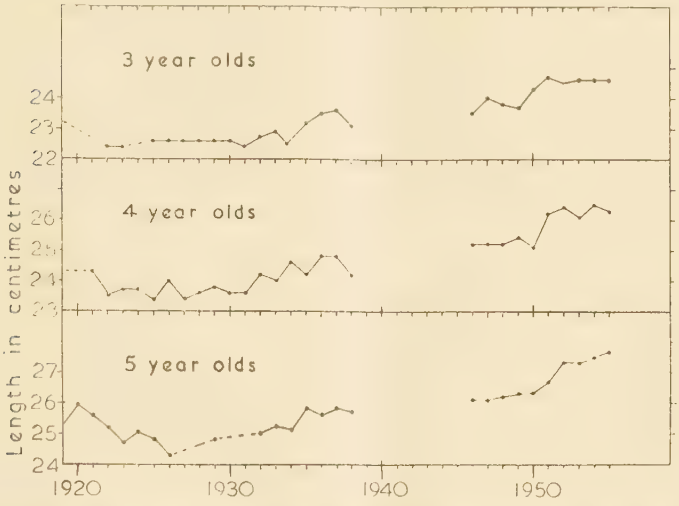

Fig. II,2: *Average lengths of three, four and five year old fish in the East Anglian fishery.*

There has been a slightly upward trend in the length of the three year old fish taken in the East Anglian fishery since about 1930. Between 1946 and 1950 the increase in length over the pre-war fish was noticeable, but in 1950 the length increased sharply by about 0·5 cm (Fig. 2). In 1951 there was a further increase in the average length of the three year old fish and this has been sustained in subsequent years. The increases in length in the older fish are best shown in the form of yearly increments (Table 1).

Table 1: *Yearly growth increments (in cm) of herring from* 1946-54.

Year	Age		
	3/4	4/5	5/6
1946			
1947	1·7	0·9	0·8
1948	1·2	1·0	0·7
1949	1·6	1·1	0·6
1950	1·4	0·9	0·7
1951	1·9	1·6	1·1
1952	1·7	1·1	0·8
1953	1·6	0·9	0·5
1954	1·9	1·4	0·8

It will be noticed that at each age the highest increment for the period was found in 1950/1.

The same trends, the increase in length of three year old fish in 1950 and the increase in length of older fish in 1951 may be shown in samples from other Southern Bight fisheries.

Fig. 3 shows the lengths of three year old and older fish as sampled at Boulogne (Ancellin, 1953), at Ostend (Gilis, 1954) and at Lowestoft. It will be noticed that although the East Anglian fish are consistently larger than those sampled at spawning at Boulogne or as spents at Ostend, the trends in change of length follow the same course in all three fisheries.

Trends in length measurements observed by Gilis (1950-5) in the central North Sea, which includes the Dogger and Gut fisheries, follow fairly closely those shown for East Anglia (Fig. 4). In the northern North Sea trawl fisheries, however, which include the Fladen fishery, the length measurements of all ages, including the three year olds, increase sharply in 1952. Thus, there is a marked difference in the timing of the length increase of

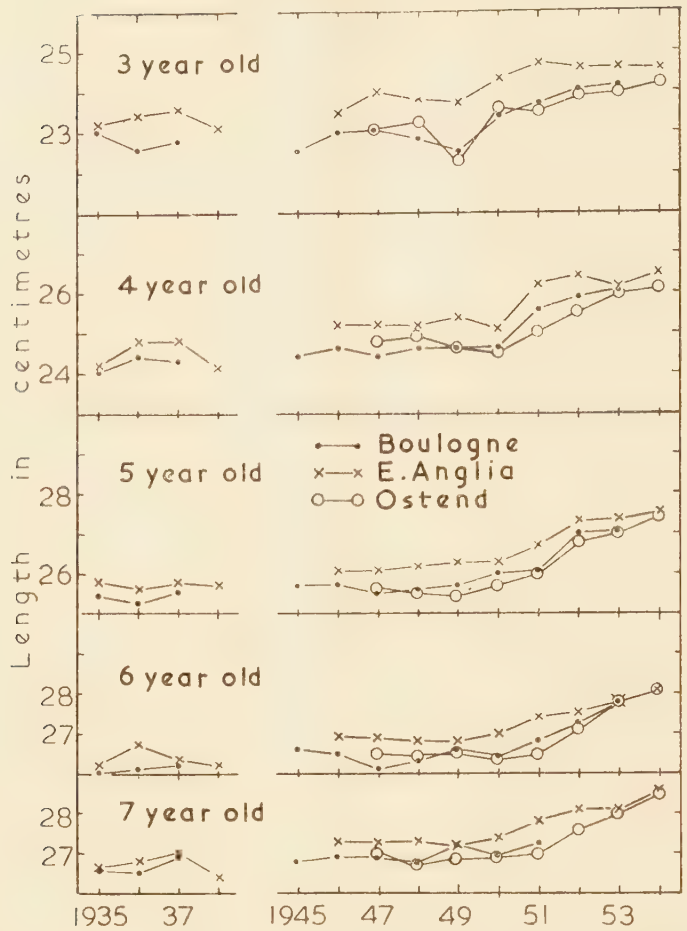

Fig. II,3: *Average length-for-age from* 1935-54 *in Southern Bight fisheries.*

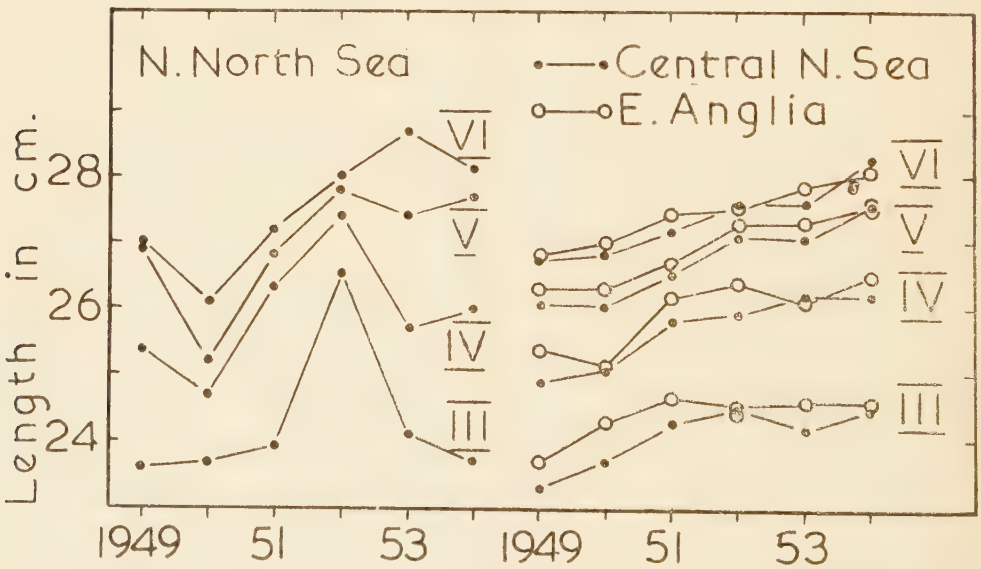

Fig. II,4: *Average length-for-age from* 1949-54 *in the northern North Sea and the central North Sea, compared with the similar measurements from the East Anglian Fishery.*

three year olds on the Fladen ground as compared with those fisheries further south; again the pattern of the growth increase over the years 1951-4 is quite different. However, one may say that the Fladen fish have also increased in length in recent years.

In the Fraserburgh and Peterhead drift-net fisheries, however, it appears that the trends in increased growth follow those off East Anglia, almost exactly (personal communication from B. B. Parrish).

So far as the Southern Bight fisheries are concerned we may make the following generalization: that the size of three year old fish increased during 1950 and that of the older fish did so in 1951.

The Change in the Nature of Recruitment

In 1952-4, three strong year classes appeared as three year old fish in the East Anglian fishery. Inspection of Table 6 in Part III of this paper shows not only that each of the year classes as three year olds is nearly three times as numerous as the mean of its predecessors but that never since 1923 had three such year classes appeared in succession.

There are alternative explanations:

(a) that a natural fluctuation without precedent in magnitude and persistence has taken place;

(b) that a change in the age of first maturity took place in 1950-1. Recruits in 1952 would be fully represented as three year olds, whereas in 1949 they would only be partly so represented, the remainder reaching the fishery as four year olds. This form of explanation was first tentatively suggested by Krefft, Schubert and Sahrhage (1955), under the term 'rejuvenation'.

That such an advance in maturity possibly did take place, as shown by an increase in the representation of recruits as three year old fish, may be demonstrated in two ways:

(a) by comparing the 1_1 distributions of three year old and four year old fish before and after 1950-1;

(b) by calculating the total number of recruits at each age over a long period of years and estimating the percentage of three year old fish in this number for each year.

From 1946-9, the numbers of three year old fish were about 55% of the numbers of four year olds that came into the fishery a year later, which included the remainder of the recruits. When the 1_1 distributions of three year old and four year old fish are compared before 1950, they are found to be markedly different, in that the smaller 1_1s are absent from the three year olds. This is because the three year old recruits consisted of the larger fish in the year class, which matured earlier and these larger fish had larger 1_1s. Hence, the small 1_1s, absent in the three year olds, constituted the group of smaller fish that came as four year olds before 1950.

If there were an advance in maturity completed in 1952, one might expect that as the smaller fish with smaller 1_1s would come in then as three year olds, then there would be no difference between the 1_1 distributions of the three year olds and the subsequent four year olds of the same year class. Fig. 5 (from Cushing and Burd, 1956) shows the 1_1 distributions of the 1945 and 1946 year classes as three and four year olds compared with the 1_1 distributions of the 1949 and 1950 year classes. In the former, before 1950, the smaller 1_1s are missing in the three year olds and in the latter, after 1952, the smaller 1_1s are present in the three year olds, there being no difference at all between the three and four year old distributions. Hence it is probable that a reduction in the age of first maturity did in fact take place, starting in 1950 and completed in 1952, for the smaller fish associated with the smaller 1_1s then appeared in the fishery as three year olds.

A further point may be made from Fig. 5. The peak in 1952 (three year olds) is at 9 cm and that in 1953 is at 10-11 cm; the former is a sample of the 1949 year class and the latter is one of the 1950 year class. Later observations show that this increase in 1_1 has been sustained; in other words, the fish in their first year increased in length at the same time as the older fish.

The second method of showing the reduction in the age of first maturity makes use of an estimate of recruitment since 1923. The percentage age distributions from 1923-55 were

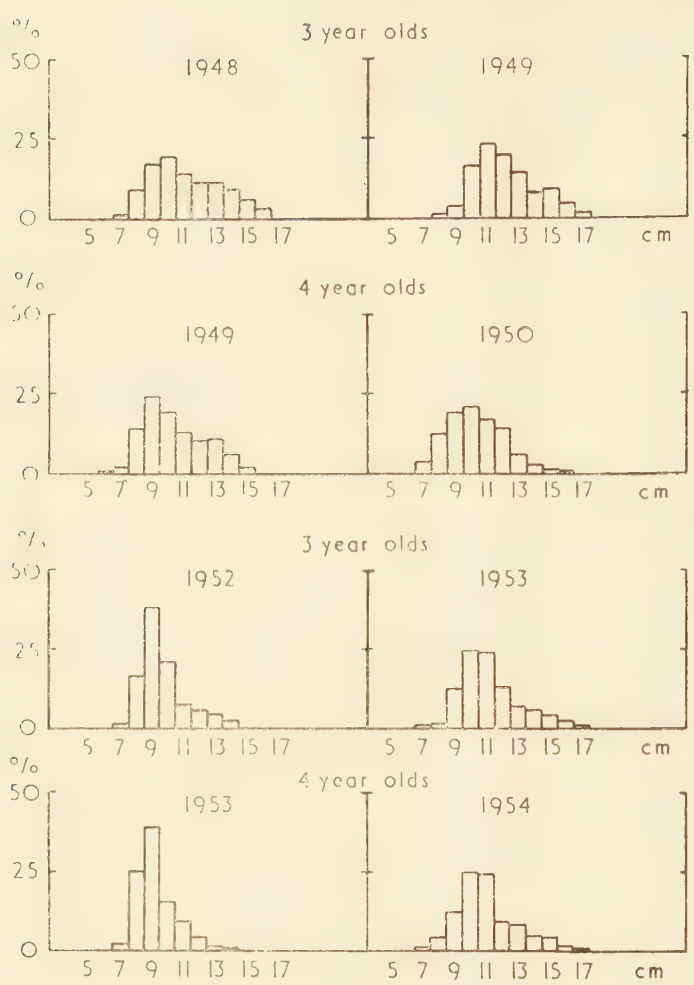

Fig.II,5

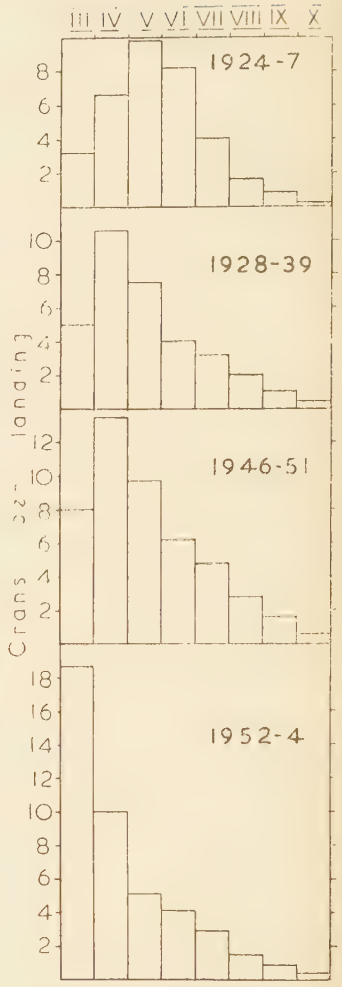

Fig.II,6

Fig. II,5: *Comparison of* 1_1 *distribution at three and four years of age for the periods* 1948-50 *and* 1952-4, *in the East Anglian Fishery.*

Fig. II,6: *Average age distributions in the East Anglian Fishery for the periods* 1924-7, 1928-39, 1946-51 *and* 1952-4. (*The age distributions are set on a comparable basis by using the percentage age composition multiplied by the number of crans per landing in each season.*

multiplied by the number of crans/landing for the appropriate season (see Table 6 in Part III). The following assumptions were made:

(a) that taking the whole series of years, full recruitment was not complete until five years old. The basis for this assumption is given in Fig. 6, where the age distributions, calculated as shown above, are grouped from 1924-7, 1928-39, 1946-41 and 1952-4. The age most abundantly represented is assumed to be that by which recruitment is complete. It will be seen that there has been a gradual shift of the most abundant age group towards the left, the younger ages. This is in itself a remarkable piece of evidence that a change in recruitment can take place; it is probable that this gradual shift is associated with the slow increase in length from 1919-50 shown in Fig. 2;

(b) that the possible bias due either to change in recruitment or to mesh selection did not appreciably affect the mortality rates from five to six years old. Average mortality rates have been used for the periods 1924-8, 1929-38, 1946-9 and 1950-5;

(c) that the natural mortality rate was 0·25; the evidence for this estimate will be presented in a later publication.

In a given year class we need to know the total number of fish at three years old, N_3.

Let the number of recruits in one year class at ages, 3, 4 and 5 be r_3, r_4 and r_5; at three years of age, let their numbers be r_3, $r_{3.1.}$ and $r_{3.2.}$.

Let the total number of fish observed in each age group in the fishery be n_3 at three years of age, n_4 at four years of age and n_5 at five years of age. n_4, the number of fish observed at four years of age in the fishery includes the recruit three year olds of the previous year which have suffered one year's fishing and natural mortality; r_4, however, consists of the recruit four year olds only.

In the first year, $n_3 = r_3$.

In the second year, $n_4 = r_4 + r_3 \cdot e^{-(F+M)}$, ... (1)

where F is the instantaneous rate of fishing mortality,

M is the instantaneous rate of natural mortality,

and t is one year ; subsequently $t = 1$.

Similarly in the third year,

$$n_5 = r_5 + r_4 \cdot e^{-(F+M)} + r_3 \cdot e^{-(F+M)2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

So, $r_4 = n_4 - r_3 \cdot e^{-(F+M)}$

and $r_5 = n_5 - r_4 \cdot e^{-(F+M)} - r_3 \cdot e^{-(F+M)2}$ ... ... (3)

The four year old recruits have suffered a year's natural mortality, i.e.,

$$r_4 = r_{3.1} e^{-M}$$

$$\therefore \; r_{3.1.} = \frac{r_4}{e^{-M}}$$

$$= \{n_4 - r_3 \cdot e^{-(F+M)}\} e^{M} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Similarly $r_{3.2} = \{n_5 - r_4 \cdot e^{-(F+M)} - r_3 \cdot e^{-(F+M)2}\} e^{2M}$ ... ... (5)

$$N_3 = r_3 + r_{3.1} + r_{3.2}$$

$$= n_3 + \{n_4 - r_3 \cdot e^{-(F+M)}\} e^{M} + \{n_5 - r_4 \cdot e^{-(F+M)} - r_3 \cdot e^{-(F+M)2}\} e^{2M} \quad (6)$$

From $n_3 = r_3$ and (1.),

$$N_3 = n_3 + \{n_4 - n_3 \cdot e^{-(F+M)}\}$$

$$\{n_5 - (n_4 - n_3 \cdot e^{-(F+M)})\} e^{-(F+M)} - n_3 \cdot e^{-(F+M)2}\} e^{2M}$$

$$= n_3 + \{n_4 - n_3 \cdot e^{-(F+M)}\} e^{M} + \{n_5 - n_4 \cdot e^{-(F+M)}\} e^{2M} \quad \ldots \quad (7)$$

The proportions of the year class at three years old, which will enter the fishery at 3, 4 and 5 years old, are given by

$$\frac{r_3}{N_3}, \; \frac{r_{3.1.}}{N_3} \text{ and } \frac{r_{3.2.}}{N_3}$$

where r and N are derived from catches/landing, as indices of abundance.

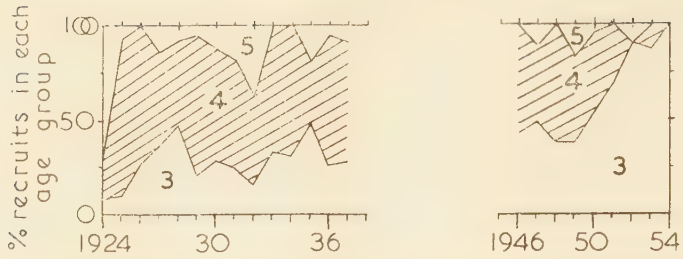

Fig. II,7: *Percentages of recruits at three, four and five years of age coming into the East Anglian Fishery since* 1924.

Expressed as percentages these proportions are given in Fig. 7 from 1924 onwards. The variations in percentage representation of three year olds are extensive, but most remarkable is the sharp rise after 1950. (It is possible that a similar rise in the representation of recruits at four years old took place in 1924-5).

The natural mortality rate might be expected to range from 0·1-0·4. At the low rate of 0·1, the percentage of three year olds will be under-estimated by using 0·25, by 4%; at the high rate of 0·4, this percentage will be over-estimated by using 0·25, by 4%.

Thus from two independent lines of evidence, it is probable that between 1950 and 1952, an advance in maturity of three year old herring took place, which resulted in their being fully represented in the fishery in 1952.

It might be said that if an advance in maturity had taken place, more two year old fish would be found in the fishery. Fig. 8 shows the length distributions of two year old fish (Bertelsen and Popp Madsen, 1953) and of three year old fish in 1948 and in 1953 off East Anglia, i.e., before and after the maturity change. It is clear from Fig. 8 that the difference

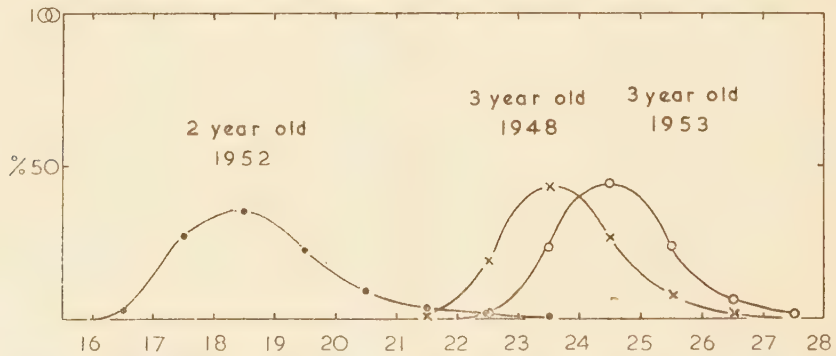

Fig. II,8: *Length distributions of two-year-old fish from the Bløden grounds; length distributions of three-year-old fish in* 1948 *and* 1953. (*in cms.*)

in length between two and three year old fish is so great that an advance in maturity through an increase in length would involve only a very slight increase in the numbers of two year olds reaching the fishery. In fact, in 1952-5, two year olds were recorded at the highest level since the fishery has been studied scientifically:

1924-50	0·005 crans/landing.
1952-55	0·25 ,, ,,

The Change in the Environment

From general considerations and see, for example, Gray and Setna's work (1931) on *Salmo irrideus*, it seemed likely that the increase in length of the herring since 1950 and 1951 was related to improved feeding conditions. Examination of the Flamborough Line

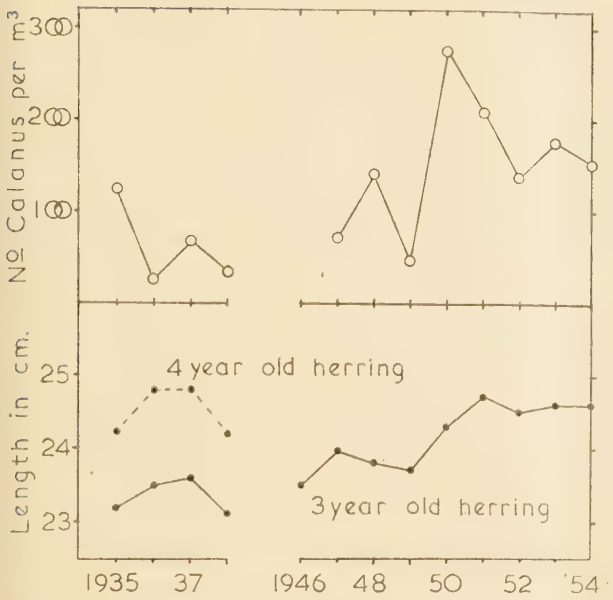

Fig.II,9

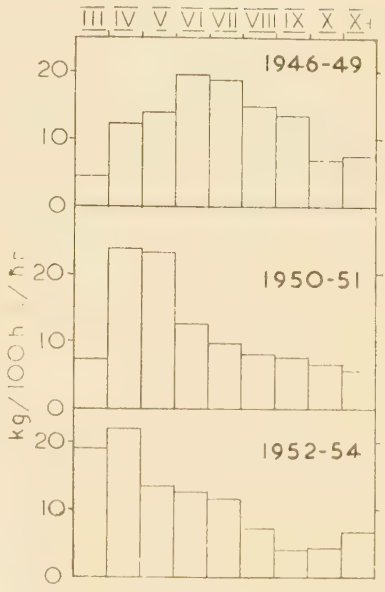

Fig.II,10

Fig. II,9: *Average length of three-year-old herring and number of* Calanus/m³ *from the Flamborough Line Stations from* 1935-54.
The average length of four-year-old herring is also given for the period 1935-38.
(*The Flamborough Line Stations used are those taken from April to September, inc.*).
Fig. II, 10: *Age distributions from the northern and central North Sea as kg./* 100 *H.P./hr., grouped in the periods* 1946-9, 1950-1, *and* 1952-4.

material of my colleague R. S. Wimpenny, has shown that a sharp increase in the numbers of *Calanus* took place in the summer of 1950 (Fig. 9). Each point represents a mean of between 15 and 30 vertical hauls taken with a Hensen net between Flamborough Head and the Dogger from April to September. It will be noted that a high number of *Calanus* was sustained during subsequent years. The larger copepodite stages of *Calanus* produce positive aggregation by herring on to *Calanus* patches (Cushing, 1955), so it is likely that the fish prefer this to other foods. As the quantity of the preferred food increased markedly in 1950, it is likely that the increase in length of three year old fish in that year and of older fish in the subsequent year is associated with it.

It has been suggested that the increased growth in length in 1950 and 1951 is an effect of decreased abundance of the herring (Andersson, 1954) and it might be suggested that the increase in numbers of *Calanus* might be attributed to the same cause. This possibility has been carefully considered, but appears to be ruled out for two reasons:

(a) the mortality of the East Anglian herring only reached the pre-war level after 1952. Fish were not larger during the pre-war period, nor were the numbers of *Calanus* high;

(b) the numbers of *Calanus* during the period 1947-8, when the fishing effort put on to the herring stocks was comparatively light, were actually a little higher than pre-war.

Hence, it is likely that the numbers of *Calanus* increased in 1950 independently of the numbers of herring and that, as a consequence, the herring increased their growth rate.

The Natural Change in the East Anglian Fishery

In 1950 the numbers of *Calanus*, the preferred food of the herring, increased by as much as three times; at the same time, the three year old fish increased in length, reaching

the length of pre-war four year olds for the first time. As these fish were so much bigger they matured younger and more of them came into the fishery at three years of age. As the improved feeding conditions were sustained, the trend towards younger maturity continued, until in 1952 the 1949 year class, the first to live all its life under the improved conditions, came in fully represented at three years old. A further effect of the natural change is that the observed loss of four year old fish dating from 1951 is accounted for and that the increased numbers of three year olds dating from 1952 is also accounted for. These events are linked with great changes in the environment. It may be that conditions of recruitment have also improved, but these are difficult to estimate because of variability and the possible effect of the industrial fishery on recruitment.

It was shown above that the increase in growth rate in 1950 and 1951 was a widespread one, extending from the Southern Bight fisheries to the Fladen ground. Hence we should also expect to find in other North Sea fisheries the same shift of the most abundant age groups towards the young end of the age distributions for the Fladen, Gut and Dogger, and Belgian trawl fisheries (Fig. 10, expressed as kg/100 H.P./hr for each age class and grouped from 1946-9, 1950-1 and 1952-4). A shift of the most abundant age groups towards the young end of the age distribution is immediately obvious. Comparing 1946-9 with 1950-4, there has also been a reduction in numbers of older fish accumulated during the war.

There is a further effect of the natural change which is that the advance in maturity is effective, as the years go on, throughout the whole age distribution, e.g., the six year old fish of 1955 onwards are comparable in abundance with the seven year old fish of earlier years. This is most important when we wish to compare age distributions before the advance in maturity with those after the change. As the Channel trawling started in strength in 1951, the year previous to which the advance in maturity was fully effective amongst the three year olds, the need is great to distinguish between the effects of fishing and the effects of the natural change.

The numbers per landing of the older age groups from 1935-55 in the East Anglian fishery are shown in Table 2; those estimates affected by the advance in maturity are in italics.

Table 2: *Numbers per landing of the older age groups from* 1935-55 *in the East Anglian fishery (in thousands)*

Year	Age Group					
	5	6	7	8	9	10
1935	1·9	12·9	2·5	3·4	1·1	0·6
1936	7·5	2·7	9·3	1·2	2·4	0·6
1937	14·2	4·2	1·2	3·5	0·7	0·6
1938	7·6	7·2	1·8	1·4	2·0	0·4
1946	11·8	8·4	7·1	6·8	2·6	1·0
1947	16·1	6·3	7·0	2·9	2·8	1·1
1948	8·8	14·1	9·3	4·4	2·6	1·1
1949	11·5	5·6	7·8	1·8	1·0	0·4
1950	14·6	7·1	3·4	3·9	1·3	0·5
1951	13·9	8·6	4·0	2·1	2·1	0·5
1952	*8·4*	10·1	5·1	2·0	1·2	0·8
1953	*4·0*	*2·9*	3·3	1·8	0·9	0·5
1954	*7·4*	*2·8*	*2·7*	2·1	1·5	0·3
1955	*4·6*	*2·5*	*0·9*	*0·8*	0·5	0·3

The effect of the maturity change may be taken into account by comparing the estimates affected by it with those a year older in some earlier period, e.g., the estimates of abundance of the five year old fish from 1952-5 may be compared with those of the six year old fish from 1946-52 or with those of the six year old fish from 1935-8.

We may make the following comparisons:

5's of 52-55 with 6's of 46-51.

6's of 53-55 + 7's of 52 with 7's of 46-51.

7's of 54-55 and 8's of 52-53 with 8's of 46-51.

Because the effect of the maturity change has been taken up in these comparisons, any reduction observed must be due to some other cause, for example, fishing. The percentage reductions for the three age groups 5, 6 and 7 of the period 1952-55 as compared with the period 1946-51 are:

5	...	...	...	27%
6	...	...	...	48%
7	...	...	...	49%

A similar comparison with the 6's, 7's and 8's of the period 1935-8, yields the following percentage reductions:

5	...	...	...	10%
6	...	...	...	11%
7	...	...	...	22%

If we take the five, six and seven year olds as representative of the older fish we may say that allowing for the advance in maturity there has been between 25 and 50% reduction in numbers comparing 1952-5 with 1946-51 and a reduction of 10-20% comparing 1952-5 with 1935-8.

APPENDIX I

The Reduction in Numbers of Older Fish due to an Advance in Maturity, when Age Distributions are compared before and after the Maturity Change

From 1946-9, the numbers of three year old fish were about 55% of the numbers of four year olds in the subsequent year.

Let the number of recruits in one year class at ages 3 and 4 be r_3 and r_4; at three years of age, let the numbers be r_3 and $r_{3.1}$.

Let the total number of fish observed in each age group in the fishery be n_3 and n_4.

In the first year, $n_3 = r_3$

In the second year, $n_4 = r_4 + r_3 \cdot e^{-(F+M)}$

$$\therefore \quad r_4 = n_4 - r_3 \cdot e^{-(F+M)}$$

where F is the instantaneous rate of fishing mortality,
where M is the instantaneous rate of natural mortality, as calculated in Tables 7 and 8, Part III,
where t is one year, $= 1$

From 1946-9, $n_4 = 100$ and $n_3 = 55$

$$\therefore \quad N_3 = r_3 + r_{3.1.} = n_3 + \{n_4 - r_3 \cdot e^{-(F+M)}\}e^M = 55 + \{100 - 55 \cdot e^{-(F+M)}\}e^M$$

where N_3 is the number of fish in a year class at three years of age.

Let $F + M = 0{\cdot}4$ (see Part III, Table 7, for average values of $(F + M)$ from 1946-9)

Let $M = 0{\cdot}25$,

then $N_3 = 136{\cdot}1$.

With recruitment constant, the numbers of a year class at for example 5 years of age, before the maturity change in 1950-1, are given by

$$\{n_3 \cdot e^{-(F+M)} + n_4 - n_3 \cdot e^{-(F+M)}\}e^{-(F+M)} = n_4 \cdot e^{-(F+M)} \quad \ldots \quad (1)$$

Similarly with constant recruitment, the numbers of a year class at 5 years of age, after the maturity change in 1950-1, are given by

$$N_3 \cdot e^{-2(F+M)} \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

So, comparing a period before the maturity change with one after it, we would expect the numbers of five year old fish to be reduced by a percentage obtained from the following fraction,

$$\left\{1 - \frac{N_3 \cdot e^{-2(F+M)}}{n_4 \cdot e^{-(F+M)}}\right\} 100$$

To estimate the effect of the maturity change on the different age groups after 1952, we must take into account the fact that in 1955 the eight year olds, as an example of the older age groups, have been affected by the maturity change for the first time. So if we compare the six year olds of 1946-51, with those of 1952-5, the latter estimate includes one observation, that of 1952, which was not affected by the maturity change. Thus, for six year olds, of 1952-5, we use three observations of the form given in (1) and one of that given in (2):—

$$\left\{1 - \frac{3\{N_3 \cdot e^{-3(F+M)}\} + n_4 \cdot e^{-2(F+M)}}{4} \cdot \frac{1}{n_4 \cdot e^{-2(F+M)}}\right\} 100$$

For seven year olds we use,

$$\left\{1 - \frac{2\{N_3 \cdot e^{-4(F+M)}\} + 2n_4 \cdot e^{-3(F+M)}}{4} \cdot \frac{1}{n_4 \cdot e^{-3(F+M)}}\right\} 100$$

where there were two year classes of seven year olds recruited before the maturity change started in 1950, and two after it.

Comparing the maturity change effect for specific mortality values;

When $(F + M) = 0{\cdot}4$, the average reduction in numbers over the age groups 5, 6 and 7 is 7%.

When $(F + M) = 0{\cdot}6$, the average reduction in numbers over the same age groups is 19%.

It is seen that if the total mortality increases, the effect of the maturity change in reducing the numbers of an age group is increased, as when the periods 1946-51 and 1952-5 are compared. (From Table 7 in Part III, $(F + M)$ in the period 1946-9 was 0·4 and from 1952-5 it reaches 0·6). Thus an indirect effect of the increased mortality is to exacerbate the effects of the maturity change.

The same method may be used to estimate the total reduction in numbers of an age group, due to both maturity change and increased fishing mortality. For 5 year old fish we use the expression,

$$\left\{1 - \frac{N_3 \cdot e^{-2(F+M)_2}}{n_4 \cdot e^{-(F+M)_1}}\right\} 100$$

where $(F + M)_1$ is the total mortality rate before the maturity change and $(F + M)_2$ is that after it.

Let $(F + M)_1 = 0{\cdot}4$, the mortality rate from 1946-9

and $(F + M)_2 = 0{\cdot}6$, the mortality rate from 1952-5.

Then adapting the formulae already given for 6's and 7's similarly the percentage reductions are,

5's	6's	7's	mean
39%	46%	52%	46%*

(*This agrees fairly well with our value of 52% already given, estimated directly from the data of Table II.)

Thus, when $(F + M)$ is increased from 0·4 to 0·6 contemporaneously with an advance in maturity, as indeed did happen, we should expect the numbers of the older age groups to be halved. This is comparable with the percentage reductions given on page 17 by a rougher method, which assumed that the age at first maturity had been reduced by one year for all the year class. The method in this Appendix assumes that the age at first maturity had been reduced by one year for part of the year class. Hence the rough method is justified.

III. CHANGES ASCRIBED TO FISHING

Introduction

It is the intention firstly to describe the recent history of the East Anglian fishery from the point of view of the landing statistics. These have been characterised by greatly declining catches. The second section deals with the changes in the age composition and the calculation of mortality rates. An estimate is also presented of the possible effect which the "industrial fishery" for small herring on the eastern nursery ground may have on the recruitment to the East Anglian fishery.

The Downs Stock

The East Anglian fishery is conducted upon Downs herring which are migrating to spawning grounds in the Southern Bight and English Channel as defined by Cushing in Part I. In addition to the fishery by the English and Scottish drifter fleets there is that of large Dutch and German drifter fleets. Since about 1951, there has also been an increasing trawling effort on the spawning areas by German, French, Dutch, Belgian, Polish and recently Icelandic fishermen. When the spawning is completed, spent herring are taken in quantity by Belgian trawlers in coastal continental waters.

Prior to the East Anglian fishery in October, it is probable that some herring that would otherwise have come to East Anglia are caught in the summer drifter fishery off the Scottish and the Northumberland Coasts.

Statistics of catches of the fisheries in Table I have been taken as giving a minimal estimate of the total catch of Downs herring in the Southern Bight.

Table 1: *Catches of the Downs herring in the Southern Bight in thousands of Metric Tons*

Year	England (Drift)	Holland (Drift)	Germany (Drift)	France (Channel only)	German, Belgian and Dutch N. Sea and Channel Trawl	Total
				(Drifters only)		
1931	116	36	18	19	2	191
1932	87	34	14	22	1	158
1933	90	39	25	27	1	182
1934	80	41	29	15	1	166
1935	105	33	22	21	9	190
1936	108	48	28	28	3	215
1937	127	58	31	28	1	245
1938	100	56	23	35	3	217
				(Trawlers only)		
1946	67	52	14	–	22	155
1947	77	57	15	7	7	163
1948	91	58	19	7	10	185
1949	59	51	19	6	3	138
1950	66	61	23	18	12	180
1951	60	59	29	4	44	196
1952	49	62	28	20	54	213
1953	51	57	30	28	83	249
1954	49	66	25	13	80	233

The data are plotted in Fig. 1, where it is seen that the total catch in 1952, 1953 and 1954 reached a similar level to that of the period 1935-38. However, whereas in 1938 the East Anglian catch amounted to just under half the total, this has been reduced to about one-fifth in 1954. Taking the two periods 1946-9 and 1950-4, there has been an increase of 34% in the total quantity of herring landed in the latter period. As can be seen from Table 1, this increase is mainly due to the trawl fishery on the spawning grounds. The high catches of 1935-38 were made in the main by large drifter fleets. It was not until 1951 that major trawling commenced on the spawning places. Complete data are available only up to 1954.

(*a*) *East Anglia*

The quantities of drift-net caught herring landed at Lowestoft and Yarmouth for the period 1924-55 are shown, in thousands of crans, in Table 2 and Fig. 2, with the numbers of landings made in each season. A high and increasing proportion of these landings are by visiting Scottish drifters.

Table 2 sets out the well-known facts that the yield of the East Anglian herring fishery has tended to decrease since 1924 and that the fishing effort has also declined.

The number of crans per landing is not wholly satisfactory as an index of abundance, because a landing may sometimes represent more than one night's fishing. Also, the cran is a volume measure and as such is inaccurate as an index of numbers. A somewhat better estimate of abundance is given by the mean number of fish per landing for each year, but this is still open to the objection to using number of landings. The means given below have been calculated from the weekly averages, which are derived from length measurements raised by the total weight landed.

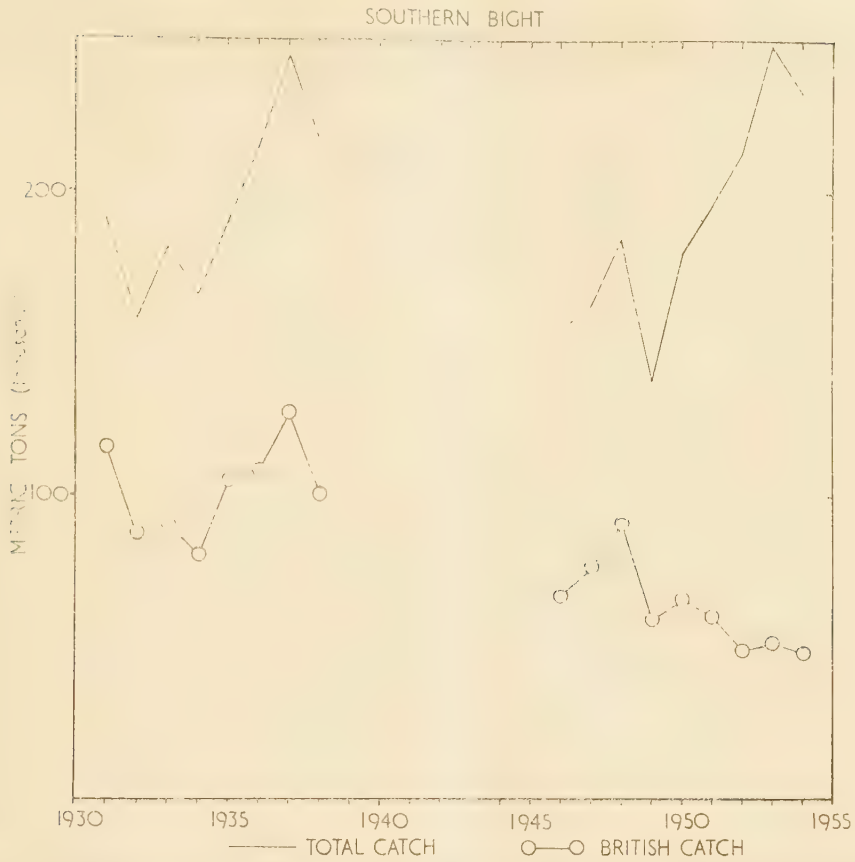

Fig. III, 1: *Yearly total catch of herring in the Southern Bight and total East Anglian catch*

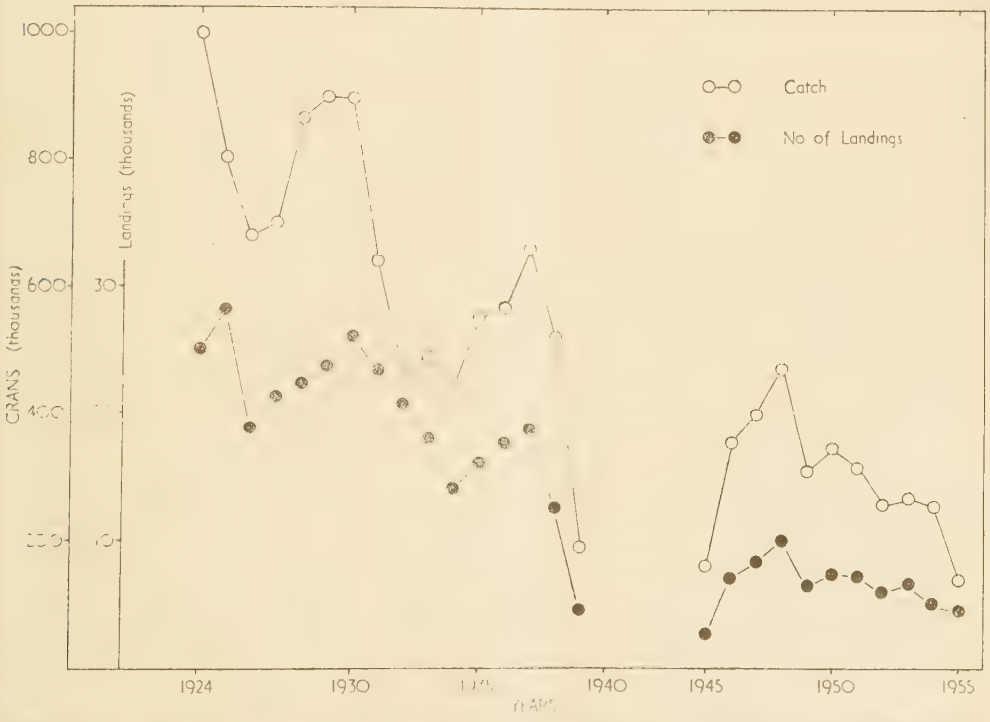

Fig. III, 2: *Total herring catch landed at Lowestoft and Yarmouth for the period* 1924-55, *with number of landings made.*

Table 2. *East Anglian drift-net catch in thousand of crans and number of landings made*, 1924-1955

	Catch (Crans/1,000)	No. of Landings
1924	1,000	25,281
1925	816	28,265
1926	682	18,892
1927	700	21,311
1928	867	22,273
1929	896	23,627
1930	884	25,986
1931	639	23,399
1932	474	20,666
1933	488	17,953
1934	441	13,855
1935	551	16,005
1936	565	17,655
1937	664	18,667
1938	523	12,484
1939	187	4,360
1945	158	2,592
1946	354	7,076
1947	406	8,295
1948	476	9,959
1949	310	6,486
1950	346	7,396
1951	316	7,308
1952	259	5,948
1953	266	6,678
1954	256	5,202
1955	114	4,665

Table 3: *Catch per effort as mean number of herring per landing at Lowestoft (in thousands)*

1935	52·0	1946	68·9	1950	63·0
1936	50·3	1947	58·4	1951	50·2
1937	49·6	1948	67·8	1952	56·4
1938	57·7	1949	61·5	1953	53·3
				1954	56·1
				1955	30·8

From that series of figures it seems clear that there was a greater abundance of herrings after the respite from fishing during the war. That affords perhaps the simplest evidence that fishing can effect the abundance of the Downs herring.

(*b*) *The November Fishery*

Table 4: *Total catches of herring in crans in October and November by drifters landing in East Anglia*

Year	October	November	Year	October	November
1947	117,710	237,423	1951	159,782	134,823
1948	170,190	285,864	1952	180,323	54,496
1949	54,675	226,134	1953	124,849	118,473
1950	177,205	147,240	1954	166,482	69,589
			1955	52,408	49,252

Cushing in Part 2 discusses the reduced landings of older fish. Their season of landings tends to be November rather than October, and in Table 4, it is plainly seen that the reductions shown in Table 2 have fallen in November rather than in October. It is not possible to compare individual years, owing to the various physical and biological factors which may render a fish more or less liable to capture, such as the effects of wind, lunar behaviour, etc. The reduction is shown to be general and is not confined to a single year.

The corresponding figures for numbers per unit landing in thousands of herring show a similar decline.

Year	October	November	Year	October	November
1946	67·2	76·6	1951	50·8	59·3
1947	53·6	65·3	1952	68·5	37·2
1948	66·5	76·9	1953	57·3	48·5
1949	38·7	85·7	1954	70·4	45·8
1950	74·1	49·2	1955	28·9	28·6
Means	60·0	70·7	Means	55·2	43·9

(*c*) *Industrial fishery for young herring*

Since 1950 an extensive fishery for small immature herring for processing to meal and oil has been developed east of the Dogger Bank. Table 5 shows the quantities of fish taken in the North Sea by trawlers from Denmark and Germany, whose statistics are available and are believed to include almost the whole of this fishery.

Table 5: *Quantities of herring caught by the Industrial Fishery, in tons (Denmark and Germany)*

Year	*Catch*
1950	5,447
1951	38,000
1952	49,000
1953	75,000
1954	103,000

The fishery takes place in two periods of the year. There is an early spring fishery which is supported by fish of O and I-group, i.e., one and two year olds. There is then a lull during the period from March to July, when the autumn fishery commences. The autumn fishery is conducted on fish 80% of which are I-group and II-group, followed later in the season—October and November—by O-group herring. The autumn fishery is the larger fishery by about five times (Bertelsen and Popp Madsen, 1953; Schubert, 1953). Schubert gives an average weight of 57·73 gm per herring for the 1953 season, which would be equivalent to about 3,000 fish per cran. That would then make the number of fish in the catch in 1954 about 1,800 million. For comparison, at 1,000 per cran, the number of fish landed in East Anglia in 1955 was 114 million. If the industrial catch were on the Downs stock alone, that fishery could be expected to cause a considerable reduction in the recruits to East Anglia, even taking into consideration that a fishing mortality would replace part of the natural mortality. Such a reduction of recruits would show in the East Anglian fishery of October, but when we turn back to the data of the previous section we find no such reduction; instead there were some very good October fisheries, until 1955. It may be that 1955 is the first of a series of years to show reduction of recruits; or it may be that a real effect on recruits was masked in 1952, 1953 and 1954 by the favourable effects of exceptionally good environmental conditions, but those are surmises, and in the meanwhile, it has to be recorded that there is as yet no significant effect discernible from the new industrial fishery. Using the method of Part II, Section 3, and the data of Table 6, calculations were made of the numbers of recruits at 3 years of age. A reduction of 6% in the numbers of recruits was found when the period 1952-5 was compared with 1946-9. This is well within the range of expected variation in year broods.

As Cushing has shown in Part I, there is good reason to believe that the Bløden area is a nursery ground for young herring from more than one North Sea spawning. Cushing refers to Bückmann (1942) who has shown that larvae from both the Channel and Dogger spawning areas are carried by currents into the German Bight, and to other considerations that make it likely that the Bløden area is the nursery for at least two groups of herring—Bank and Downs.

Recapitulation

1. The Southern Bight catch of Downs herring has risen in recent years and in 1953 has exceeded the catches made before the war.

2. In East Anglia since the war there has been a reduction in the total catch, the number of landings, the catch per effort and in the numbers of fish per landing in November. The degree of reduction is set out in the following table:

	Average Number of Landings	Average Catch in crans	Average Catch/effort (in thousands of fish)	Average numbers per landing in November (in thousands of fish)
1946–50	7,842	378,000	63·9	70·7
1951–55	5,960	242,000	49·4	43·9
% reduction	24	36	23	38

The reductions in quantity and numbers are evidence of fishing affecting abundance, admittedly to a rather uncertain degree.

3. Since 1950, there has been a rapid increase in the quantity of immature herring taken for industrial purposes, from which, however, no significant effect on recruitment has yet been demonstrated.

Age Composition of the Downs Herring

In estimating the annual yield of herring from each age group two methods have been used. Table 6 (latter part) shows the numbers of herring per landing by age groups, calculated by the methods of Hodgson (1939) from 1935 onwards. For years before 1935 the numbers of herring per landing are not available. The second method used, giving information from earlier years, is given in Table 6 (first part) where the age composition (per cent) has been multiplied by the average catch per landing in crans for each year from 1924-38. Comparison between the two methods may be made from 1935-8, the information for which is given for both.

(*a*) *Mortality Rates*

Apparent mortality rates for each age group have been calculated for the period 1935 to 1955 on the basis of the average landing data of Table 6 (latter part.) The mortalities have been calculated from the expression $\log_e N_V/N_{V+1}$, where N_V is the abundance of herring in a given year class in year v and N_{V+1} is the abundance of the same year class one year later (Beverton and Holt, 1956). The estimate obtained is of mortality from all causes, ($F + M$ in their notation).

Table 6: *East Anglian herring. Crans per landing at each age*
(*% age composition* × *total crans per landing*)

Year	Age Group									
	2	3	4	5	6	7	8	9	10	10+
1924	–	1·7	9·5	11·6	10·3	3·2	0·9	2·1	0·3	–
1925	–	1·1	4·9	6·2	8·0	7·0	1·0	0·1	0·5	0·1
1926	0·0	1·1	8·6	14·5	4·6	3·8	3·1	0·2	0·0	0·0
1927	0·1	9·0	3·2	6·8	9·9	2·0	1·4	0·3	0·0	–
1928	0·0	3·7	16·2	2·3	5·2	8·7	1·6	0·9	0·3	0·0
1929	–	3·0	5·5	14·1	2·3	4·5	7·2	0·8	0·3	0·1
1930	0·0	4·5	10·8	3·5	7·4	1·5	3·1	2·7	0·3	0·1
1931	–	2·0	10·0	6·5	1·2	4·0	0·8	1·9	0·7	0·2
1932	–	4·5	4·9	6·9	2·9	0·8	1·9	0·3	0·6	0·2
1933	–	1·2	13·4	3·8	5·0	1·6	0·7	1·0	0·2	0·2
1934	–	4·1	2·7	14·7	3·0	5·4	1·0	0·5	0·4	0·1
1935	–	10·6	9·9	1·2	8·0	1·5	2·1	0·7	0·2	0·1
1936	–	3·0	12·5	5·2	1·9	6·5	0·9	1·7	0·4	–
1937	–	9·4	8·2	10·4	3·1	0·9	2·6	0·5	0·4	0·2
1938	–	4·4	23·2	5·3	5·1	1·2	1·0	1·4	0·2	0·1

Table 6 : (contd.) *Numbers of herring per landing in each age group for Lowestoft and Yarmouth ('000s omitted)*

Year	Age Group									
	2	3	4	5	6	7	8	9	10	10+
1935	–	16·8	15·8	1·9	12·9	2·5	3·4	1·1	0·6	0·5
1936	–	4·4	18·0	7·5	2·7	9·3	1·2	2·4	0·6	0·6
1937	–	12·9	11·1	14·2	4·2	1·2	3·5	0·7	0·6	0·5
1938	–	6·3	33·0	7·6	7·2	1·8	1·4	2·0	0·2	0·1
1946	–	8·2	22·3	11·8	8·4	7·1	6·8	2·6	1·0	0·3
1947	–	9·3	12·9	16·1	6·3	7·0	2·9	2·8	1·1	0·4
1948	–	13·5	15·2	8·8	14·1	9·3	4·4	2·6	1·1	0·7
1949	–	12·4	26·5	11·5	5·6	7·8	1·8	1·0	0·4	0·3
1950	–	11·3	18·9	14·6	7·1	3·4	3·9	1·3	0·5	0·4
1951	–	9·4	13·3	13·9	8·6	4·0	2·1	2·1	0·5	0·3
1952	–	19·2	9·2	8·4	10·1	5·1	2·0	1·2	0·8	0·2
1953	0·3	27·7	10·9	4·0	2·9	3·3	1·8	0·9	0·5	0·3
1954	1·0	25·2	18·3	7·4	2·8	2·7	2·1	1·5	0·3	0·3
1955	0·0	10·7	8·2	4·6	2·5	0·9	0·8	0·5	0·3	0·3

Mortality rates obtained in this way are variable, particularly from year to year, e.g.:

	3/4	4/5	5/6	6/7	7/8	8/9	9/10
1951/2	0·02	0·46	0·32	0·52	0·69	0·56	0·97
1952/3	0·57	0·83	1·06	1·12	1·04	0·80	0·88

and sometimes are unreliable due to sampling error of a poor year class, e.g., that of 1930. Similar variations, which may be due to differences in availability, are found in mortality calculations for a trawl fishery like that for plaice (see Table 10 in Beverton, 1950), and mere inspection of Table 6 suggests that there are changes in mortality to be brought out by appropriate treatment of the data. For that purpose, mean mortality coefficients have been calculated for three periods, 1935-8, 1946-9 and 1950-5; these are shown in Table 7.

Table 7: *Mean mortality coefficients* ($F + M$)

Year	Age Group	
	5/6	6/7
1935–8	0·30*	0·66
1946–9	0·40	0·13
1950–5	0·67	0·68

It is thought that the values between 5 and 7 years of age represent the best estimates, because recruitment is complete by 5 years old in all years and numbers of fish older than seven are subject to large sampling error and perhaps biased by mesh selection. Allowing

*Includes a negative mortality in 1935–36, probably a sampling error in the poor year class of 1930, as can be seen in Table 6.

in Table 7 for the supposed sampling irregularity in the 5 6 group, it is seen that mortalities from 1950-5 are greater than from 1946-9 and about the same as those of pre-war years.

Turning now to the very recent years, since trawling in the Channel greatly increased, from 1951 (Table 1) the average mortalities of 5/6 and 6/7 increase to 0·81 in the years 1952 to 1955.

(*b*) *The effort on the Downs stock of herring*

It is difficult to estimate the fishing effort exerted on the Downs herring stock, partly because the effort figures themselves are incomplete, and partly because there is an unspecified proportion of effort expended on the Downs stock in the feeding areas north of the Dogger.

Table 8: *Southern Bight total catch and effort*

Year	(a) Southern Bight Catch Thousands of Metric tons (Table 1)	(b) East Anglian Catch Thousands of Metric tons	(c) East Anglian Effort (Landings)	$\frac{c \times a}{b}$ Southern Bight Effort. Equivalent Drifter Landings
1935	190	105	16,005	28,961
1936	215	108	17,655	35,147
1937	245	127	18,667	36,011
1938	217	100	12,484	27,090
1946	155	67	7,076	16,370
1947	163	77	8,295	17,560
1948	185	91	9,959	20,246
1949	138	59	6,486	15,171
1950	180	66	7,396	20,171
1951	196	60	7,308	23,873
1952	213	49	5,948	25,856
1953	249	51	6,678	32,604
1954	233	49	5,202	24,736

However, in Table 8 the total Southern Bight catches of Table 1 have been converted to equivalent drifter landings by means of the East Anglian catch and effort statistics. From this Table it can be seen that the equivalent effort involved on the Southern Bight fishery since 1950 has reached a similar level to that of the immediate pre-war period. The period 1946-9 is characterised by lower effort figures.

Thus the changes in the values of $(F + M)$ seen in the previous section are mirrored in the changing effort and total catch in the Southern Bight fishery. No marked increase in the equivalent effort figures has taken place since 1952, corresponding with the increase in $(F + M)$ to 0·81. However, in this period between one-third and one-half of the total Southern Bight catch has been derived from the increase in trawling, as can be seen from Table 1. It is therefore possible that in converting the trawl catches by the drifter factor of landings per ton an underestimate is being made of the effort involved.

In the summer drift net fisheries on the feeding grounds in the northern North Sea there has been an increase in total catch. At Fraserburgh alone (Parrish, 1956) since 1950 the effort expressed as number of landings, and the total catch have been almost doubled.

This increased effort may have some effect on the Southern Bight fisheries as it is believed that Downs herring occur in these feeding fisheries (Wood, 1936).

Thus there has been a change in the nature of the fishery, in that since 1937 there has been an increased effort, to a great extent on the spawning grounds in the Straits of Dover, and to an unknown extent on the feeding grounds north of the Dogger. This change is related to a contemporaneous increase in $(F + M)$ (Table 7) and a decline in catch per effort (Table 3).

Recapitulation

Total apparent mortality of adult fish in the Downs stock of herring has in recent years become much higher than in the years immediately after the second world war. This is a change that can most easily be ascribed to a change in fishing that has taken place at the same time, namely the increase in trawling of adult herring in the neighbourhood of the English Channel. There was also a period of high mortality rates, and high catches and low numbers per effort in the years prior to 1939. Without claiming fully to understand the events of that period, the data afford some support for the main conclusion of this part: that in the failure of the November fishery the increased trawling of recent years has played a substantial part.

IV. THE EFFECT OF FISHING ON THE STOCK OF DOWNS HERRING

The Industrial Fishery on the Eastern Nursery Ground and its Effect on Recruitment

The best estimate available gives the result that since the industrial fishery started in 1951, the recruitment in 1952-5 has been reduced by about 6% as compared with the period 1946-9. To resolve the difficulties inherent in this sort of estimate, estimates of mortality rates in the industrial fishery are necessary, as well as estimates of numbers in the various year-classes.

The Effect of the Maturity Change

It was pointed out in Part II that the change in maturity can increase the stocks available by only a small amount, i.e., by that due to one year's natural mortality. This is almost an irrelevant point as compared with the change in the nature of the fisheries.

1. As more three year old fish are available for catching, the fishery off East Anglia has remained quite good in October, because in this month only the 3's and 4's come in. Again, the fisheries in the northern North Sea have probably increased their yields for the same reason, that more three year old fish are available. This does not necessarily mean that the stocks have increased either off East Anglia in October or in the northern North Sea in summer; it could be that the fish are being caught younger and in different fisheries.

2. If the fish are caught a little earlier in their lives, a fishery depending on older fish like the November drift net fishery practised by the Dutch, the Germans, the English and the Scots, will necessarily suffer in some degree, great or small, depending on total mortality, which seems to include a high fishing mortality (Part III, p. 26).

The Effect of Fishing on the Mature Fish

Since 1952, the numbers per landing of 5's, 6's and 7's have been halved and their numbers are now lower than those of pre-war years. (Table 2, Part II.)

There are two changes associated with this:

1. The catch of herring in the Southern Bight has increased by 30% since 1950, due to a new trawl fishery in the region of the Straits of Dover (Table 1, Part III). At the same time catches of herring in the northern and central North Sea increased considerably, as shown in the tables of catch per landing for Scottish east coast ports (Parrish *et. al.*, 1954). As the Downs herring spawn in the region of the Straits of Dover and feed in the northern to central North Sea, great increases in the catch of this stock have apparently taken place since 1952.

2. There have been also changes in efficiency:

(a) in the use of the echo sounder as a search instrument in the drift-net fisheries since about 1950;

(b) in the effectiveness of bottom trawls by their rig since 1949.

Ideally, we ought to be able to link the two changes together, showing that increases in catch and mortality are equally consequences of increases in effort. We cannot do this, because fishing effort cannot yet be properly allotted by fisheries, nor by gears.

But if total mortality rate has doubled (compare that of 1946-9 with 1952-5, Part III), it is possible that the effect of fishing will be disastrous before we obtain sufficient statistics.

In the meanwhile, the following interpretation seems the best available: if fishing had remained at the 1946-9 level, it is possible that the maturity change would not have been noticed very much on the older fish, and that the effect of the maturity change became so noticeable, because of the increased mortality, dating from 1952, and associated with high total landings. So we have reason to believe that the reduction in numbers of older fish, comparing 1952-5 with 1946-51, is partly a direct effect of fishing and partly an indirect one.

On that interpretation, the effect of the maturity change is to alter the character of the fisheries, to amplify good fortune in the younger feeding fisheries and to exacerbate misfortune in the spawning fisheries.

General Conclusion

1. The Downs herring is a useful concept representing a possible "management unit" with greater or less exactitude[1].

2. There has been an advance in maturity that brings the herring into the fishery sooner in their life history and that makes an appreciable reduction in the older age groups[2]. But an increase in total mortality has made this reduction more noticeable[3].

3. The data, such as they are, indicate that fishing has also reduced the abundance of older age groups directly:

(a) because the reduction in recent years is more than would be accounted for by the advance in maturity[4],

(b) because apparent total mortality has been relatively high in two periods of high landings, one of which, 1935-8, was before the change in maturity.

4. The shortage of older age groups reduces the November fishery more than the October[5] and operators of all kinds are hurt commercially by the shortening of the East Anglian drift-net season. Evidence that fishing could have such a great effect is new in this fishery, and the scientists concerned in this laboratory are apprehensive about the recent changes[6] considered in the light of data submitted in these papers.

(1) Part I, p. 7

(2) Part II, p. 16

(3) Part II, p. 17

(4) Part III, p. 25

(5) Part III, p. 23

(6) Part III, p. 28

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